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BRAYTON CYCLE CAVITY RECEIVER DEVELOPMENT

QUARTERLY REPORT)

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OCTOBER 1963 – DECEMBER 1963

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TRW ELECTROMECHANICAL DIVISION

THOMPSON RAMO WOOLDRIDGE INC.

CLEVELAND, OHIO

2282945

ER-5736

BRAYTON CYCLE CAVITY RECEIVER DEVELOPMENT

QUARTERLY REPORT

Technical Management
NASA-Lewis Research Center
Solar and Chemical Power Branch
Attn.: J. A. Milko (86-1)

OCTOBER 1963 — DECEMBER 1963

TRW ELECTROMECHANICAL DIVISION
THOMPSON RAMO WOOLDRIDGE INC.
CLEVELAND, OHIO

NOTICE

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1.0 PROJECT OBJECTIVES

The Brayton cycle cavity receiver development program as presently planned consists of three phases. Phase I is being performed currently and features both a design study of the full-scale flightweight unit and a material compatibility investigation with lithium fluoride as the corrosive salt. Phase II is contemplated to consist of construction and ground test of the flightweight unit. Phase III is planned as the endurance test of the flightweight unit. The ultimate objective of the program is to demonstrate a one year endurance capability of the flightweight unit in a ground test.

2.0 PROJECT OBJECTIVES FOR THE REPORTING PERIOD OF OCTOBER 1, 1963 THROUGH DECEMBER 31, 1963 (REPEATED FROM THE PREVIOUS QUARTERLY REPORT)

During the quarter from October through December, effort will be directed toward accomplishing these tasks:

1. The preliminary design analysis will be continued to identify single orbit designs for the 300-nautical mile and the synchronous orbits.
2. The small-scale experiments will be performed and are scheduled for completion.
3. The cavity surface temperature control and aperture closure study will be initiated.
4. The fluoride properties investigation will be completed.
5. The reliability effort will be continued.
6. The first 2500-hour furnace test will be initiated with capsules made from the selected materials.

3.0 PROJECT PROGRESS DURING THE REPORTING PERIOD

3.1 Task I - The Design Study

3.1.1 Overall Progress

The project schedule for Task I is presented as Figure 1. The influence of the technical redirection by NASA after the presentation of 30 August, 1963 can be observed from the schedule. The preliminary design analysis had to be essentially repeated for new operating conditions. Therefore, the preliminary design analysis for the desired single orbit operation was not completed until 1 November, 1963. The small-scale experiments were started about 1 September, but expediting was not pushed until a crash program was instituted about 1 November. Despite the crash program, two of the tests must be repeated because of a premature tube failure and faulty thermocouples. It is anticipated that these tests will be completed 1 February, 1964. Test data reduction and analysis will require at least another month.

The cavity surface temperature control and aperture closure study was initiated at the conclusion of the preliminary design analysis. This portion of the study is continuing and is scheduled to be completed at the time of the full scale layout completion. The fabrication process study, stress analysis, reliability comments, and design analysis are being performed for the full scale flightweight layout. Three potential full scale concepts were evolved as a result of the preliminary design analysis. These concepts are being critically evaluated to determine the best concept. The best single concept will be examined to determine the structural thicknesses required for one year's endurance. It is now anticipated that the full scale design layout will be complete 1 March, 1964. The reliability studies will also be completed at that time.

The above schedule indicates the rough draft of the topical report will be submitted to NASA on or about 1 April.

3.1.2 Preliminary Design Analysis

The preliminary design analysis for a cavity receiver intended to operate in a single orbit was completed as shown in Figure 1. Cavity receivers designed for the primary orbit of 300 nautical miles have a lower shade time requirement at 36 minutes nominal than the multiple orbit receivers at 70 minutes nominal. Thus, less lithium fluoride is needed and the spacing between tubes as well as the spacing between the shells can be less.

These packaging requirements were coupled with the tubing design procedures described in the first quarterly progress report, ER-5579, to arrive at three potential concepts. These concepts are shown in Figures 2, 3, and 4. Figure 2 illustrates a hemispherical container; Figure 3 depicts a conical container; Figure 4 indicates a cylindrical container. The concepts are under critical review to determine the optimum concept. The major dimensions of the concepts are listed below:

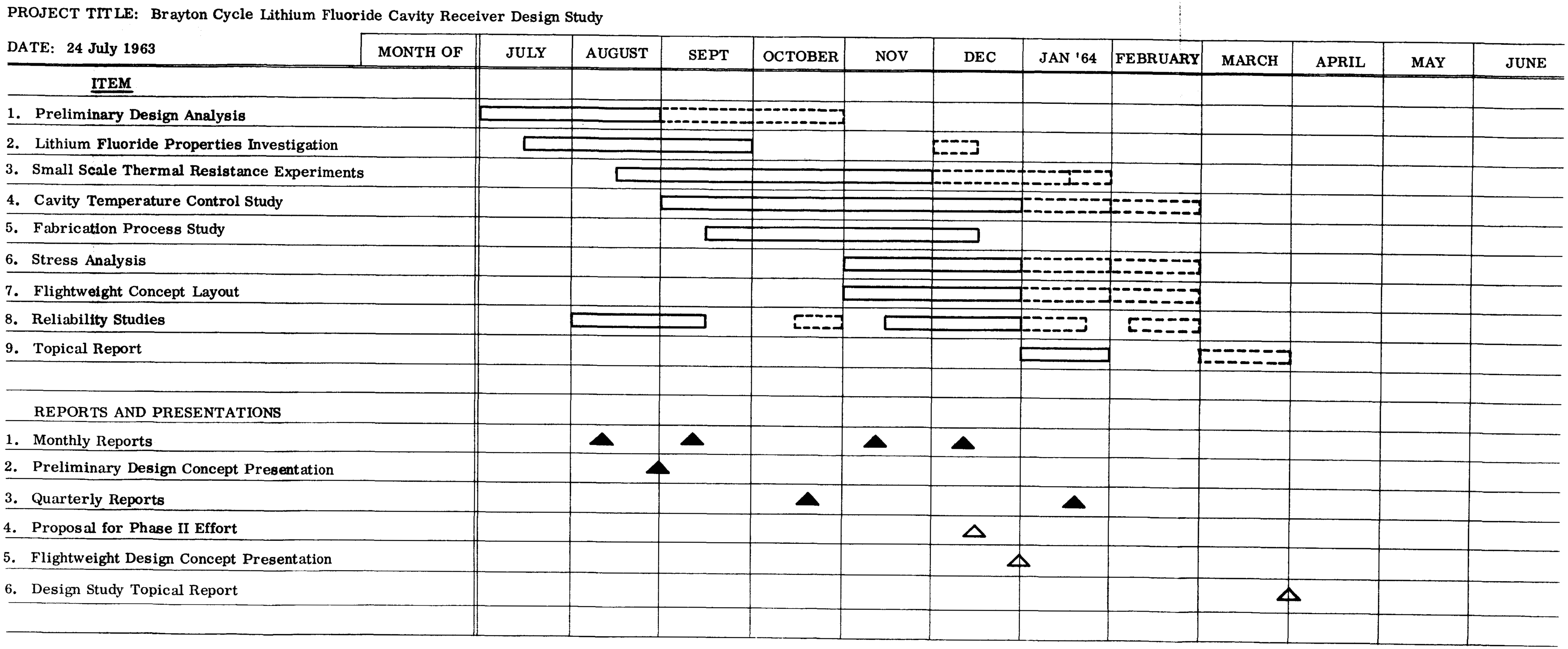

PROJECT TITLE: Brayton Cycle Lithium Fluoride Cavity Receiver Design Study
DATE: 24 July 1963
MONTH OF
JULY
AUGUST
SEPT
OCTOBER
NOV
DEC
JAN '64
FEBRUARY
MARCH
APRIL
MAY
JUNE
ITEM
1. Preliminary Design Analysis
2. Lithium Fluoride Properties Investigation
3. Small Scale Thermal Resistance Experiments
4. Cavity Temperature Control Study
5. Fabrication Process Study
6. Stress Analysis
7. Flightweight Concept Layout
8. Reliability Studies
9. Topical Report
REPORTS AND PRESENTATIONS
1. Monthly Reports
2. Preliminary Design Concept Presentation
3. Quarterly Reports
4. Proposal for Phase II Effort
5. Flightweight Design Concept Presentation
6. Design Study Topical Report

FIGURE 1

PRELIMINARY DESIGN CONFIGURATION OF A SINGLE ORBIT CAVITY RECEIVER WITH A HEMISPHERICAL FLUORIDE CONTAINER

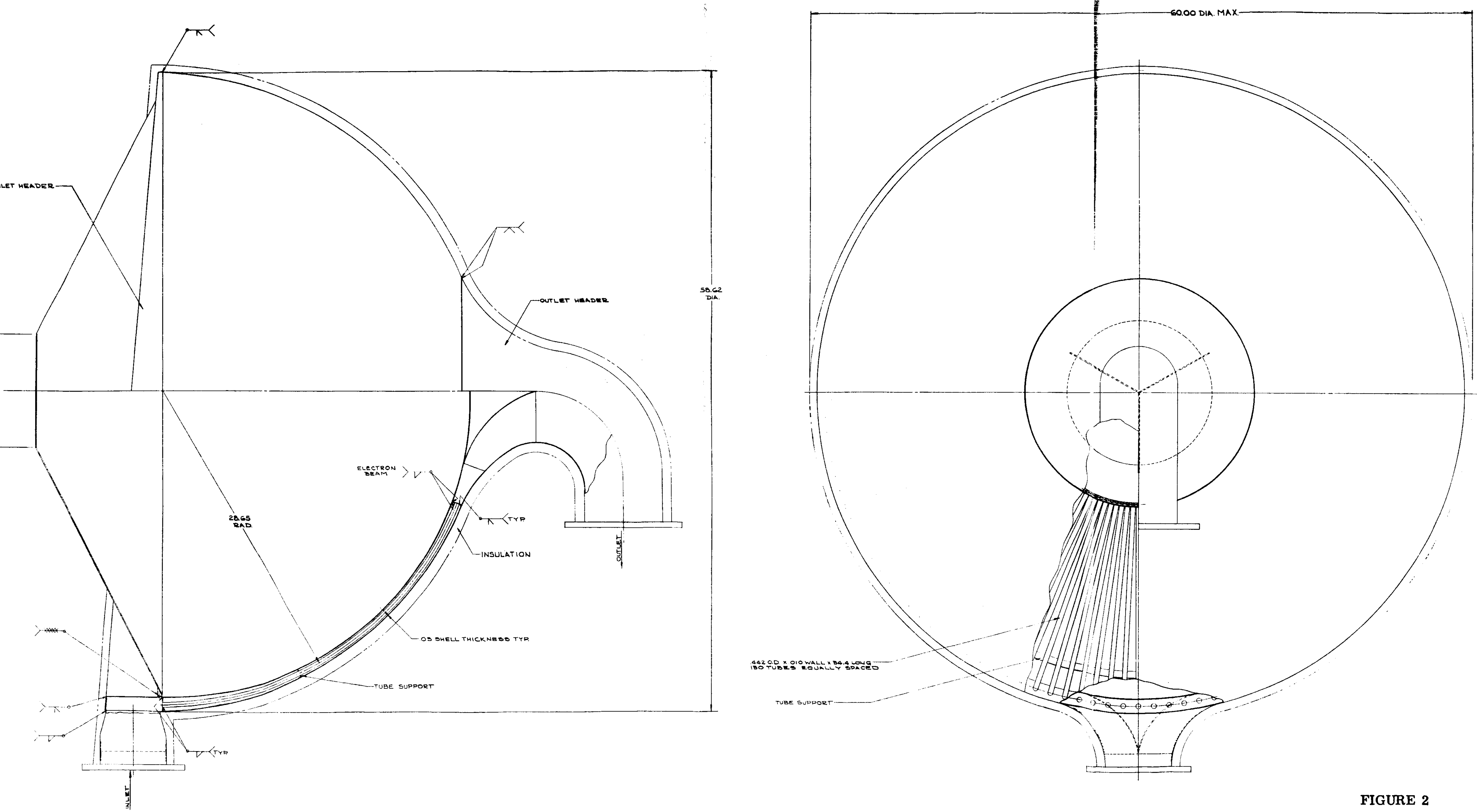


FIGURE 2

PRELIMINARY DESIGN CONFIGURATION OF A SINGLE ORBIT CAVITY RECEIVER WITH A CONICAL FLUORIDE CONTAINER

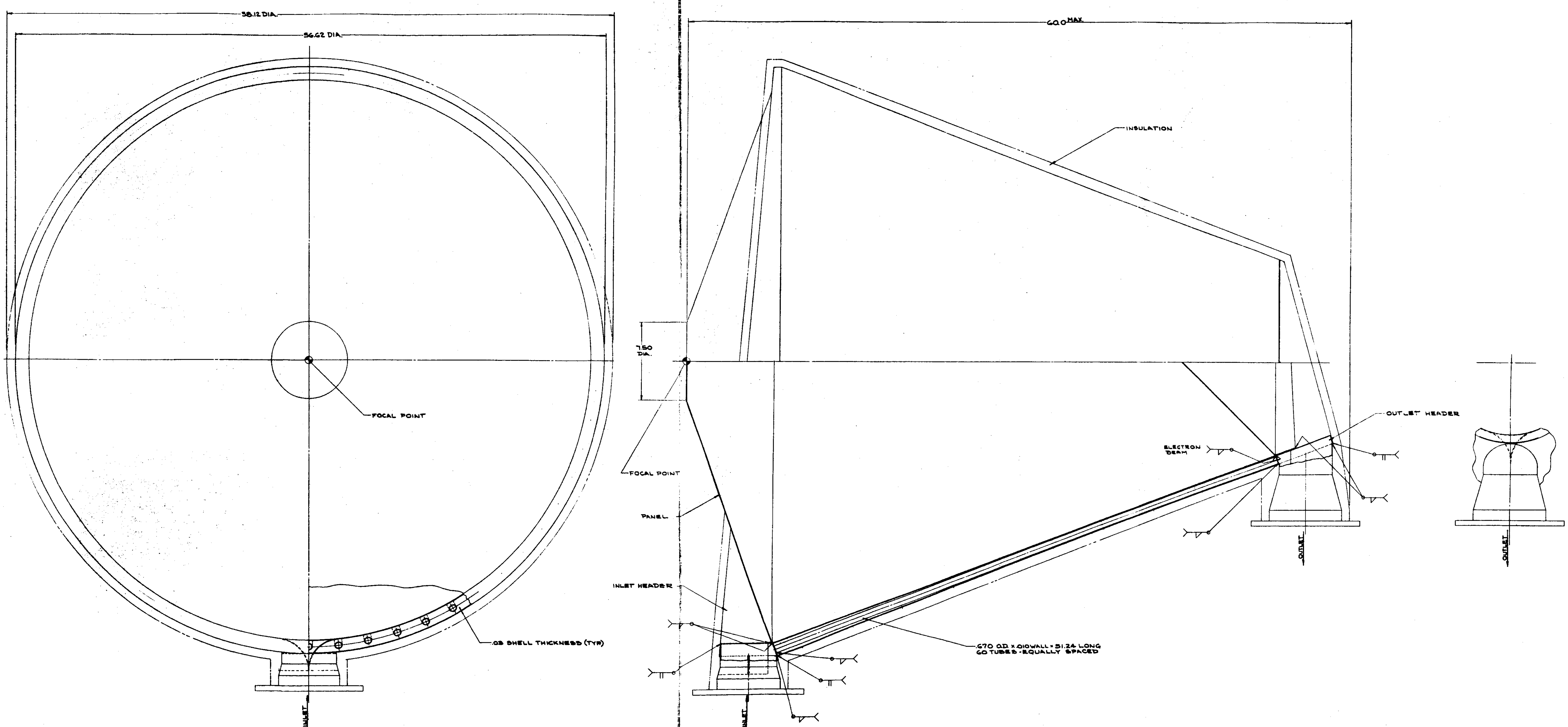


FIGURE 3

PRELIMINARY DESIGN CONFIGURATION OF A SINGLE ORBIT CAVITY RECEIVER WITH A CYLINDRICAL FLUORIDE CONTAINER

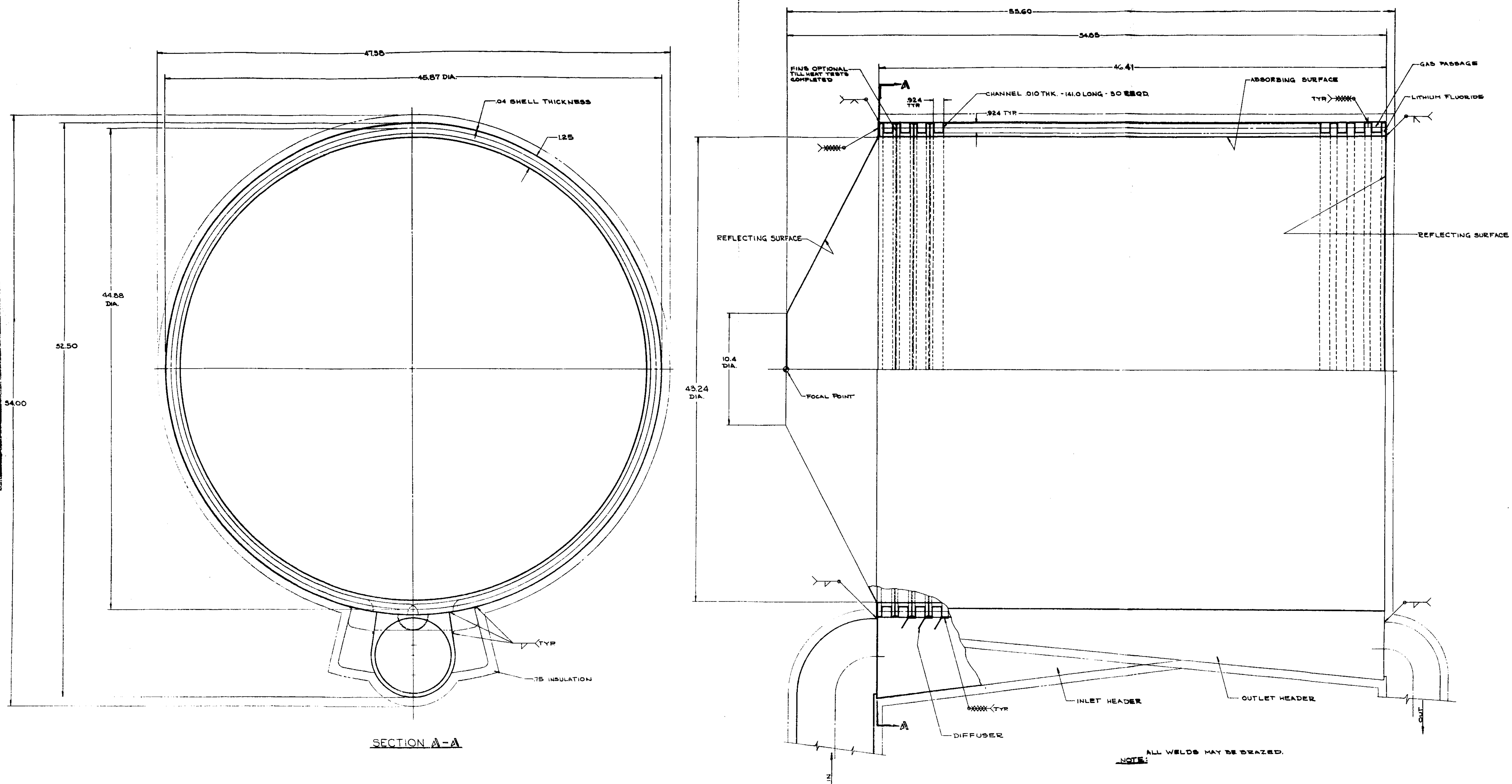


FIGURE 4

Type	Hemisphere	Cone	Cylinder
Tube Length, ft	2.87	4.27	11.72
Tube Diameter, in.	0.422	0.65	0.914
Tube Number	130	60	30
Cavity Diameter, ft	4.78	4.51	3.6
Receiver O.D., ft	5.0	4.83	3.95

3.1.3 Full Scale Flightweight Design

The activity on the full scale flightweight design has been concentrated on review of the concepts discussed and selection of the optimum concept. Engineering, reliability, manufacturing, and design personnel are contributing to this review. On determination of the best concept, the selected layout will be completed with all thicknesses and joint designs examined and specified by stress considerations.

3.1.4 Alternator Design Requirements

The NASA-Lewis Laboratory has specified the four possible cycle conditions listed in Table I. The division of effort was specified as approximately two-thirds of the effort on condition 3 and the remainder divided among the other conditions. Of the other conditions, it is understood that condition 2 is of the most interest to NASA.

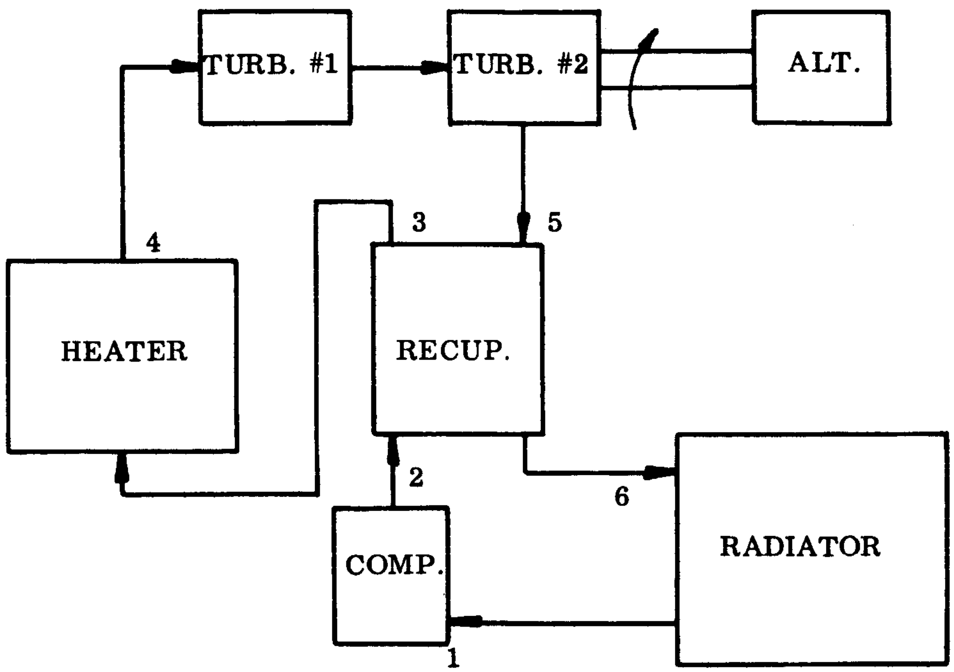
The performance changes from the basic condition 3 to the other conditions are under continued study. Preliminary results indicated that some changes in the gas side design criteria would be encountered. However, later results show that within the limits of the calculation accuracy, no change is encountered in the gas side design criteria. This situation is considered rather startling and will receive further study.

Typical gas side parameters are shown in Figure 5 for a moderate temperature ratio. Design problems would be simplified if a single set of gas side parameters could be employed for all 4 conditions given in Table I.

The shade time requirement in the nominal 300 nautical mile orbit is 36 minutes and in the synchronous orbit is 70 minutes. Thus, additional lithium fluoride must be provided in the synchronous orbit. This demands that the physical shape of the units be altered for different orbits but the gas side design criteria may be constant.

Other factors which must be given serious consideration are the amount of shadow on the collector and the increased efficiency required for the 20-foot diameter collector. These factors have not been analyzed sufficiently to date to permit further comment.

TABLE I. NASA SOLAR BRAYTON CYCLE CONDITIONS



	Conditions 1	2	3	4
Mirror Dia., ft	20	20	30	30
Orbit	300 mi.	SYNC.	300 mi.	SYNC.
P_1, psia	2.67	4.04	6.00	9.09
P_2, psia	6.13	9.29	13.80	20.90
P_3, psia	6.10	9.24	13.72	20.79
P_4, psia	5.85	8.86	13.17	19.95
P_5, psia	2.99	4.53	6.73	10.19
P_6, psia	2.92	4.42	6.57	9.95
Mass Flow, lb/min.	16.31	24.72	36.69	55.62
Power Input, KW	18.24	27.65	41.04	62.21
Net Power Output, KWe	3.56	5.39	8.00	12.13

Turbulent Flow, $\frac{\Delta t_g}{\Delta t_m} = 2.75$, $K_T = 1.95 \times 10^{11}$

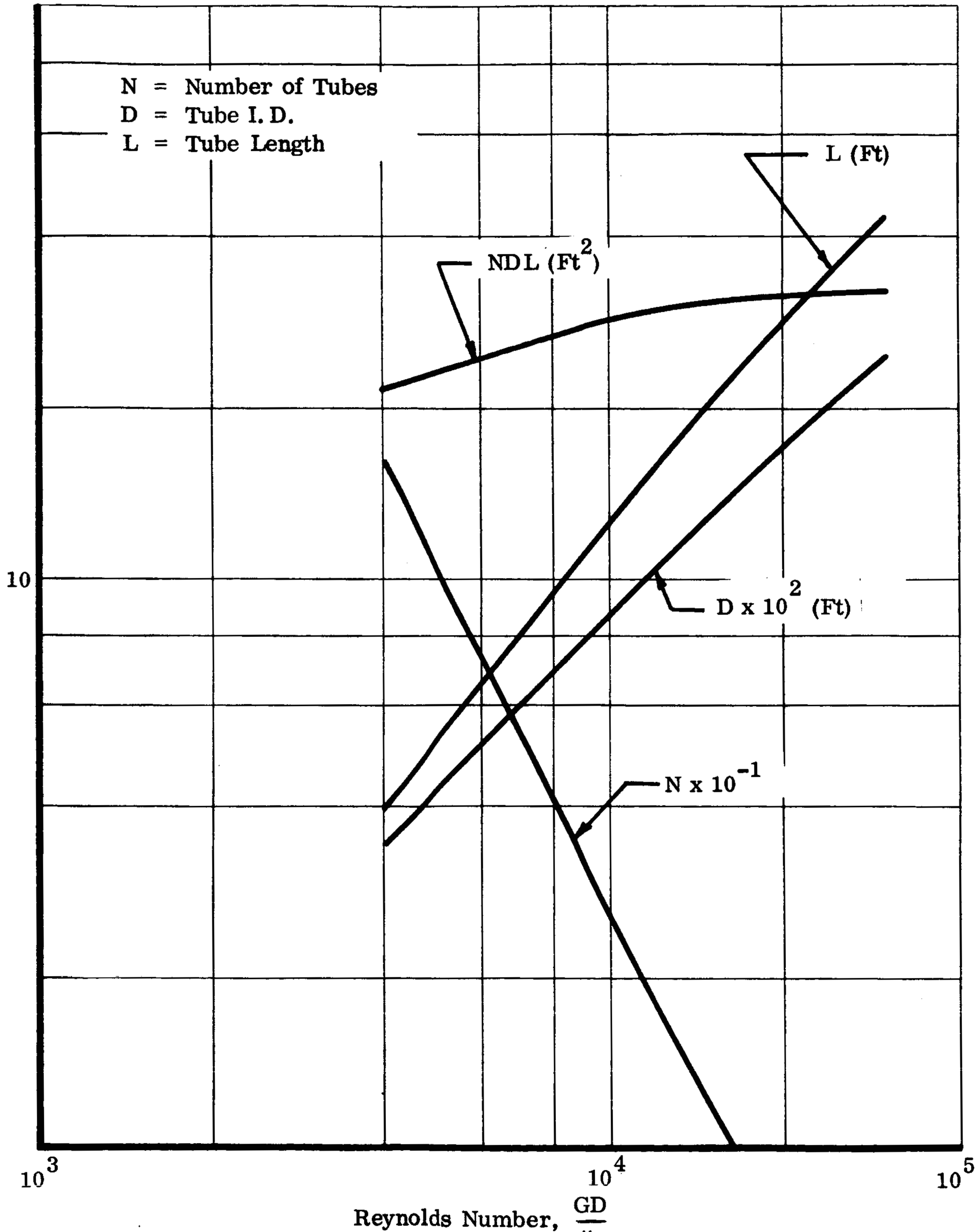


FIGURE 5 - HEATER TUBE PARAMETERS FOR TURBULENT FLOW IN CIRCULAR TUBES AT MODERATE $\Delta t_g/\Delta t_m$ (= 2.75)

3.1.5 Lithium Fluoride Properties Investigation

The investigation on lithium fluoride properties was completed during the quarter. The information obtained will be submitted in the topical report.

3.1.6 Small-Scale Experiments

The small-scale experiments conducted on this project are intended to determine

1. The thermal conductivity of lithium fluoride in the liquid and solid states near the melting point.

2. The heat input possible to lithium fluoride containers with several forms of extended surface.

3. The heat release characteristics of lithium fluoride to a gas coolant.

4. Insight into the melting and freezing characteristics of lithium fluoride and the resultant void formation.

Several modules have been constructed and tested on this program as of 1, January, 1964. They are listed below.

Module No.	Type	Test Purpose
1	Plain	Thermal Conductivity
2	Plain	Heat Input
3	Plain	Heat Release
4	Thin Fins	Heat Input
5	Thick Fins	Heat Input

Several other modules, in the last stages of processing, are:

Module No.	Type	Test Purpose
6	Large Cell Honeycomb	Heat Input
7	Small Cell Honeycomb	Heat Input
8	Plain, Narrow Annulus	Heat Release

All tests are scheduled to be completed by 1 February.

The testing has proceeded rapidly since the crash program was instituted. The testing has not been without incident, however. The initial testing on Module No. 1 was completed before the data were reduced and completely analyzed. Apparent thermal conductivity values were obtained; these were much higher than had been anticipated. Data analysis indicated faulty thermocouple readings. It was later determined that several additional thermocouples were faulty. Because of this error, it is necessary to repeat the testing on Module No. 1. It is anticipated that this testing will be accomplished early in January, 1964.

During preliminary testing of Module No. 2, liquid lithium fluoride rose in a small bleed tube to a level above the heater and froze. Ultimately, the lithium fluoride in the tube caused the tube to fail. The exact mechanism of failure has not been established at press time, but metallographic examination is in process. A considerable amount of lithium fluoride was lost from the container. The lost lithium fluoride attacked the top, sides, and bottom of the container, combined with the Min-K insulation, and attacked the quartz tube heating elements. Module No. 2 was subsequently refilled with lithium fluoride and all test objectives accomplished in a second test.

The bleed tubes on the other modules have been welded shut after filling with lithium fluoride, at a height below that of the heater. No further problems have been encountered with the bleed tubes. The testing of the other modules has demonstrated the unusual ability of the lithium fluoride to crawl up a 3/4 in. OD tube to a height of several feet. This action is not completely understood, but is under continued investigation. It is most prevalent during the initial stages of the cooling cycle after rapid heating. All test objectives on the modules tested to 1 January have been achieved. No difficulties are currently foreseen to prevent the attainment of all test objectives.

3.1.7 Cavity Surface Temperature Control and Aperture Closure Study

The cavity surface temperature control and aperture closure study is in process. As of 31 December, 1963 no finalized concepts have been evolved. This study will continue during the coming quarter.

3.1.8 Reliability Studies

The proposed reliability plan has been printed and is now ready for distribution. The reliability effort will continue to aid in the full scale flightweight concept selection and failure predictions of the selected concept.

PROJECT TITLE: Lithium Fluoride Corrosion and Material Compatibility Investigations

DATE: 1 November 1963

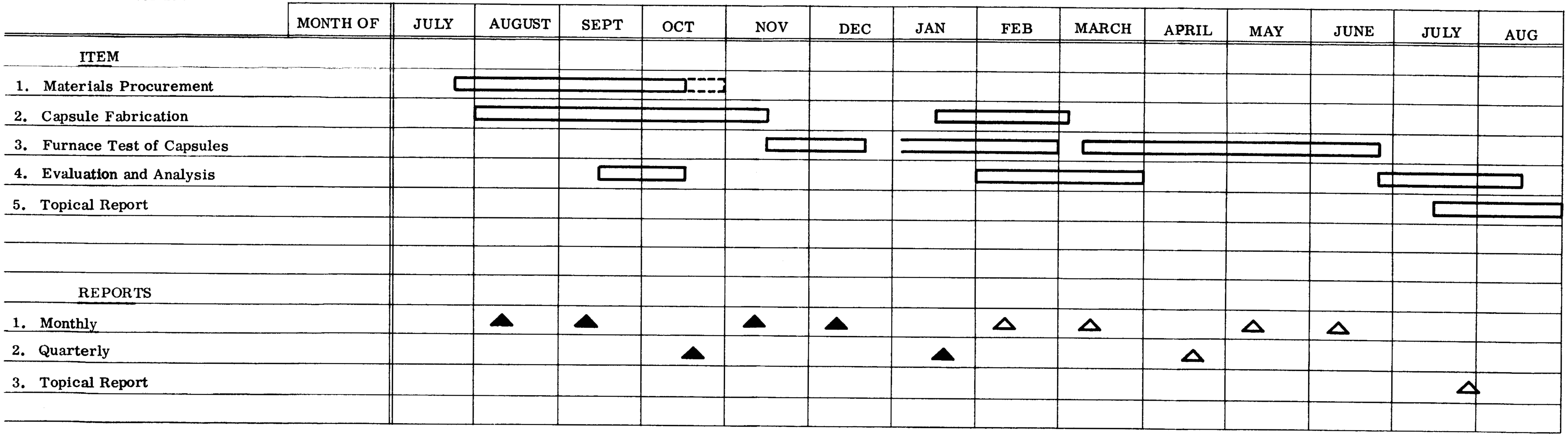


FIGURE 6

The capsule container was removed from the furnace after cool-down. It was immediately apparent that about one-eighth of the container had been completely destroyed. The container walls are 1/8-inch Hastelloy X. The inside of the container looked almost as disastrous. After the capsules were removed from the container, it was found that three Rene 41 capsules had failed. All three had holes near weld areas. There was no lithium fluoride left in any of the three capsules. Evidently, one or more of the capsules leaked. The events which followed were catastrophic. At press time, neither the cause nor the exact time of failure are known. Specimens taken from the failed capsules and a fourth Rene 41 capsule are being prepared for metallographic examination; the cause of failure may become evident then.

4.0 CURRENT PROBLEM AREAS

Three problem areas exist at press time. These are the selection of the full scale concept and resultant design layout, completion of the small-scale experiments and resultant data reduction and analysis, and the continuation of the first 2500-hour furnace test. A concentrated effort is being made in each of these areas to maintain schedule and obtain completion on time. Four test capsules must be replaced and all capsules installed in a new container. Two capsules each of Waspalloy and Hastelloy N are being prepared with longitudinal seam welds. Waspalloy filler rod is being used on the former and Hastelloy W rod on the latter.

5.0 PLANNED DIRECTION OF EFFORT FOR THE NEXT QUARTER

During the next quarter, effort will be directed towards accomplishing these tasks:

1. Completion of the full scale flightweight concept layout.
2. Completion of the small-scale experiments, including data reduction and analysis.
3. Completion of the cavity surface temperature control and aperture closure study.
4. Completion of the design comparisons for the four conditions specified.
5. Completion of the reliability studies for Phase I.
6. Continuation of the first 2500-hour furnace test.
7. Preparation of the rough draft for the topical report on the design study.

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